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POINT SOURCE REPRESENTATION OF ANTENNAS AND OBSTACLES. (U)  
JAN 77 J PERINI, J CHOU

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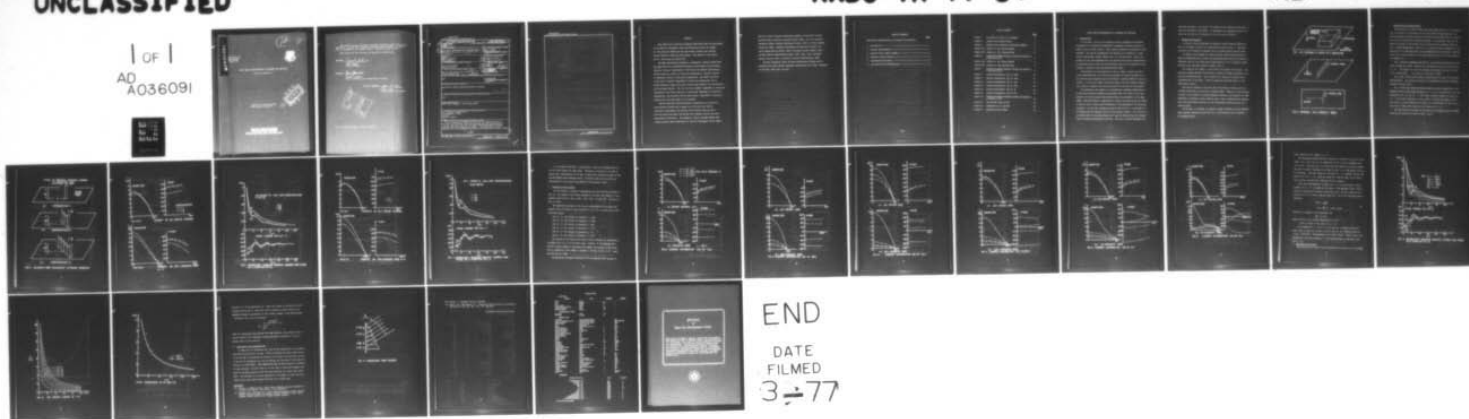
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Phase Report  
January 1977



POINT SOURCE REPRESENTATION OF ANTENNAS AND OBSTACLES  
Syracuse University

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AIR FORCE SYSTEMS COMMAND  
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## PREFACE

This effort was conducted by Syracuse University under the sponsorship of the Rome Air Development Center Post-Doctoral Program for NAVSEC. Mr. Tony Testa of NAVSEC was the task project engineer and provided overall technical direction and guidance. The authors of this report are Dr. Jose Perini and Jason Chou.

The RADC Post-Doctoral Program is a cooperative venture between RADC and some sixty-five universities eligible to participate in the program. Syracuse University (Department of Electrical and Computer Engineering), Purdue University (School of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering), and State University of New York at Buffalo (Department of Electrical Engineering) act as prime contractor schools with other schools participating via sub-contracts with the prime schools. The U.S. Air Force Academy (Department of Electrical Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the Naval Post Graduate School (Department of Electrical Engineering) also participate in the program.

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Further information about the RADC Post-Doctoral Program can be obtained from Jacob Scherer, RADC/RBC, Griffiss AFB, NY, 13441, telephone AV 587-2543, COMM (315) 330-2543.

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## POINT SOURCE REPRESENTATION OF ANTENNAS AND OBSTACLES

### 1. Introduction

In the report "Point Source Radiation Pattern Synthesis by Iterative Techniques" [1] a method was presented to synthesize radiation patterns of planar arrays of point sources. More recently Raschke and Sterling [2] have proposed the idea of representing the superstructure elements of a ship such as deck houses, stacks, fences, etc., by vertical wires. One of the authors [3] has then suggested that all antennas and wires be represented by an equivalent point source and the techniques used in [1] be applied to the problem of optimally locating antennas aboard ships.

The difficulty of this approach is that in order to obtain the point source representation of the wires and antennas, the entire problem has to be solved by some technique such as the Method of Moments (MOM) for every iteration. If the total number of wires is large, then the procedure becomes very costly in computer time and may preclude the solution of the problem.

The purpose of this report is to investigate a possible simplification of the above problem by making the hypothesis that "all wires of the same obstacle will have current distributions which are essentially of the same shape. They will differ in magnitude by a factor  $K\lambda/d$  and in phase by  $2\pi d/\lambda$ ". If this is true, it will only be necessary at the beginning of the iterative procedure to solve the considerably smaller MOM problem of the antennas to be located and one "typical" wire for each obstacle present. The currents in all other wires of the same obstacle will then be derived from the "typical" one by the above hypothesized relations. This will continue throughout the

synthesis procedure. At the end, the problem can be resolved by MOM again to check the accuracy of the result. If necessary, the recomputed typical currents can be used as a starting point for a few more iterations.

## 2. Antenna with Obstacle

A situation often encountered in shipboard antenna design problems is that of an antenna in front of a deck-house as shown in Fig. 1. The whole structure will initially be assumed over an infinite perfect ground plane.

To simplify the treatment of these problems, Raschke and Sterling [2] made the hypotheses that (a) only the conducting plate facing the antenna is important, and (b) this plate may be represented by a set of equally spaced parallel wires (parasite wires) as shown in Fig. 2.

The parasite wire length  $L$  is the same as the height of the plate. The spacing  $s$  between adjacent wires should be chosen as large as possible to reduce the computation work. Yet it cannot be so large as to become a poor representation of the plate. Previous experience has shown that  $s = \lambda/8$  yields good results.

The current induced in each wire when the antenna is driven can be accurately calculated by the method of moments (MOM). However, if this approach is used in the problem of locating shipboard antennas, one execution of a MOM algorithm is required at each iteration step. This is expensive and unnecessary since approximate currents for the intermediate iteration steps will serve as well.

In the next two sections, we propose a simple relation to obtain approximate parasite currents for any value of  $d$ , the distance from the antenna to the parasite wires.

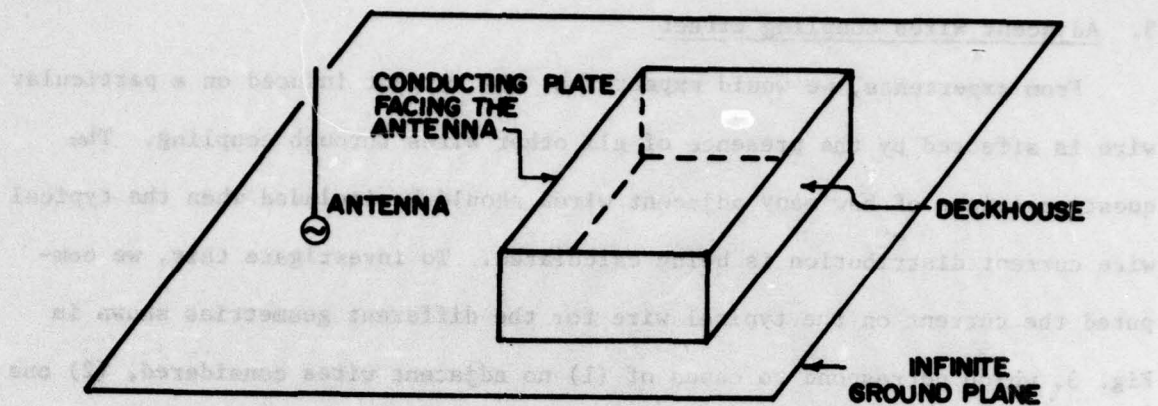


FIG. 1 AN ANTENNA IN FRONT OF A DECKHOUSE

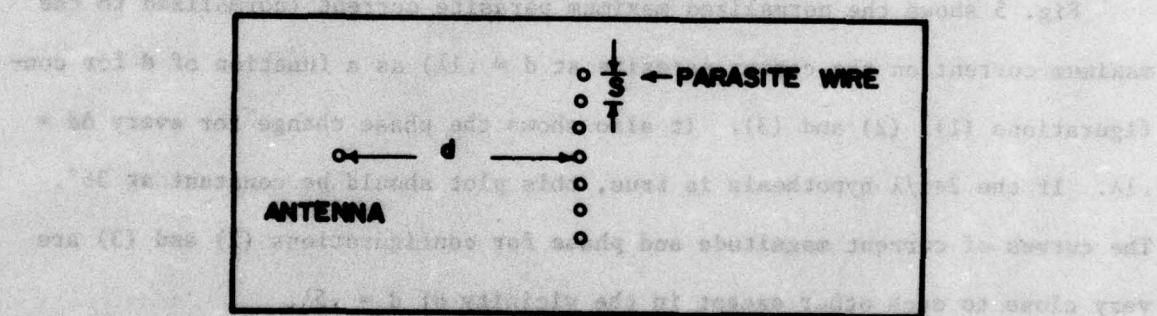
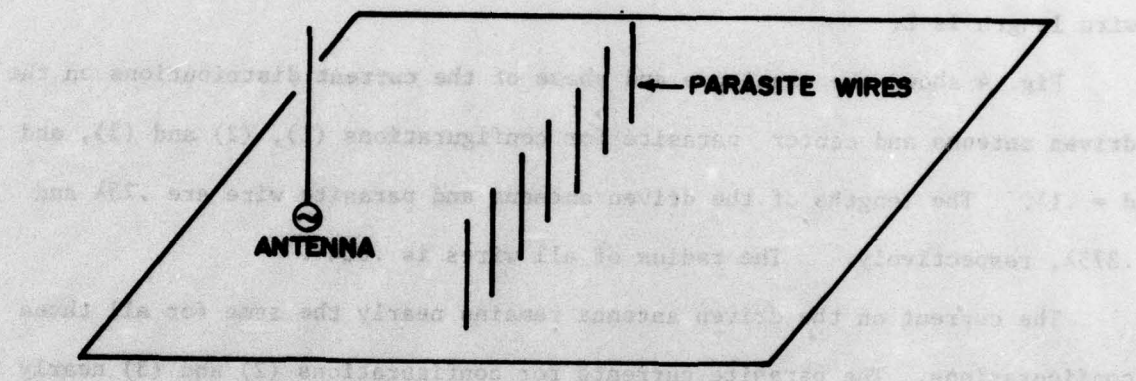


FIG. 2 ANTENNA WITH PARASITE WIRES

### 3. Adjacent Wires Coupling Effect

From experience, we would expect that the current induced on a particular wire is affected by the presence of all other wires through coupling. The question arises of how many adjacent wires should be included when the typical wire current distribution is being calculated. To investigate this, we computed the current on the typical wire for the different geometries shown in Fig. 3, which correspond to cases of (1) no adjacent wires considered, (2) one adjacent wire on each side, and (3) two adjacent wires on each side. The distance from a driven antenna to the center parasite wire is  $d$  and the parasite wire length is  $L$ .

Fig. 4 shows the magnitude and phase of the current distributions on the driven antenna and center parasite for configurations (1), (2) and (3), and  $d = .1\lambda$ . The lengths of the driven antenna and parasite wire are  $.25\lambda$  and  $.375\lambda$ , respectively. The radius of all wires is  $.004\lambda$ .

The current on the driven antenna remains nearly the same for all three configurations. The parasite currents for configurations (2) and (3) nearly coincide with each other.

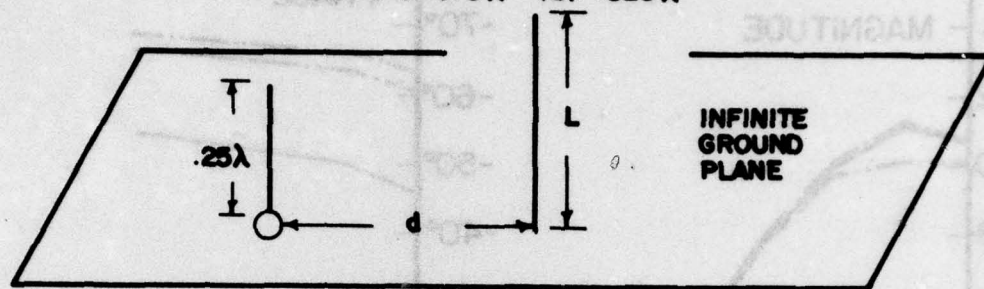
Fig. 5 shows the normalized maximum parasite current (normalized to the maximum current on the center parasite at  $d = .1\lambda$ ) as a function of  $d$  for configurations (1), (2) and (3). It also shows the phase change for every  $\Delta d = .1\lambda$ . If the  $2\pi d/\lambda$  hypothesis is true, this plot should be constant at  $36^\circ$ . The curves of current magnitude and phase for configurations (2) and (3) are very close to each other except in the vicinity of  $d = .5\lambda$ .

The same procedure was used for the case of the parasite wires of length  $.325\lambda$  and the results are shown in Figs. 6 and 7.

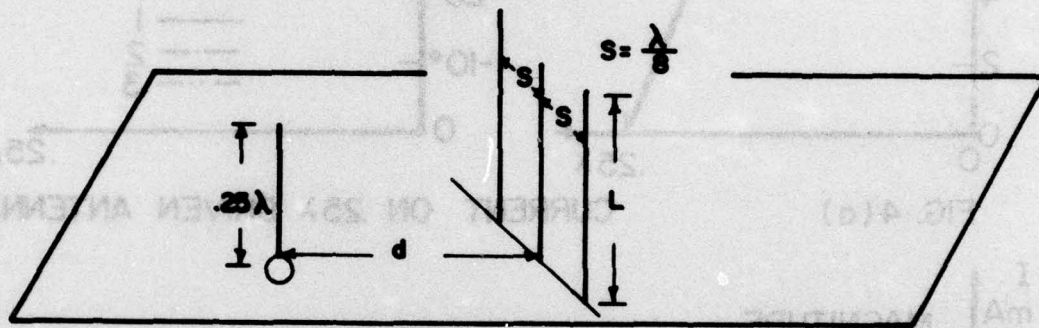
# STUDY OF PARASITE ANTENNA CURRENT

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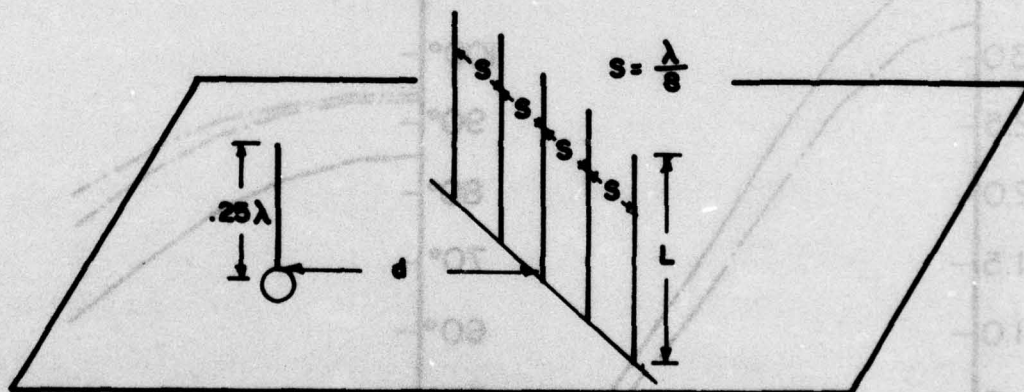
$L = (A).375\lambda$  (B).  $.325\lambda$



(a) CONFIGURATION (1)

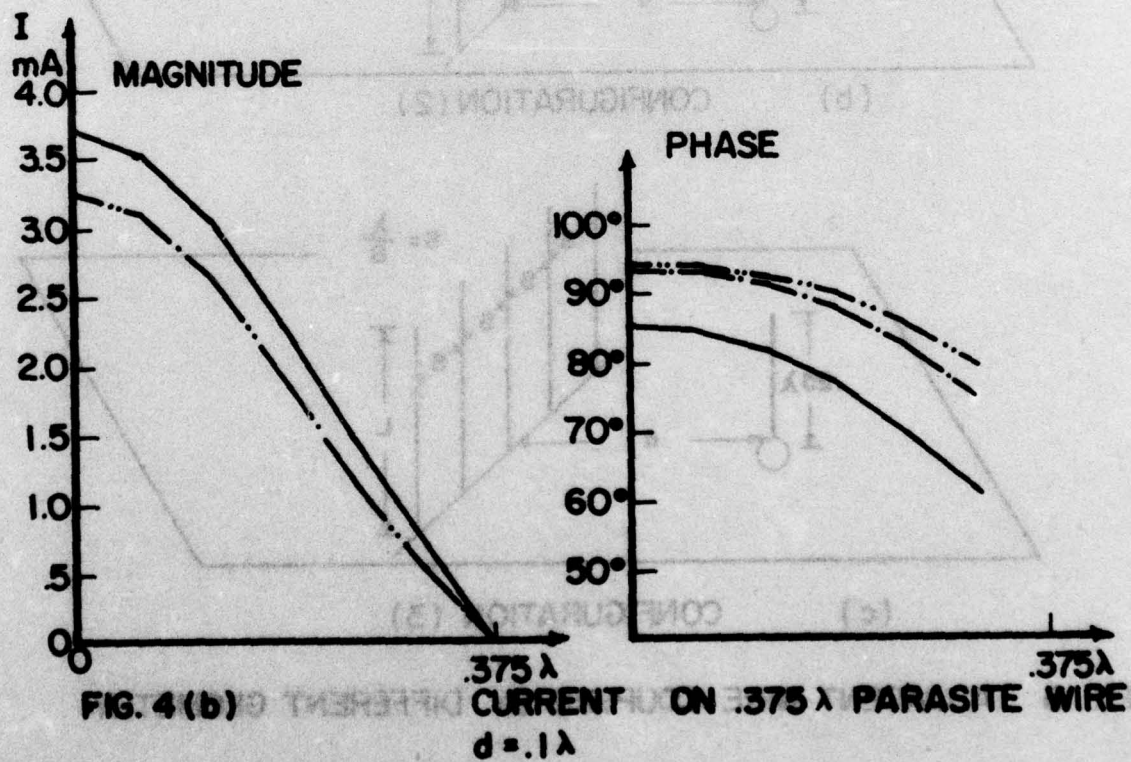
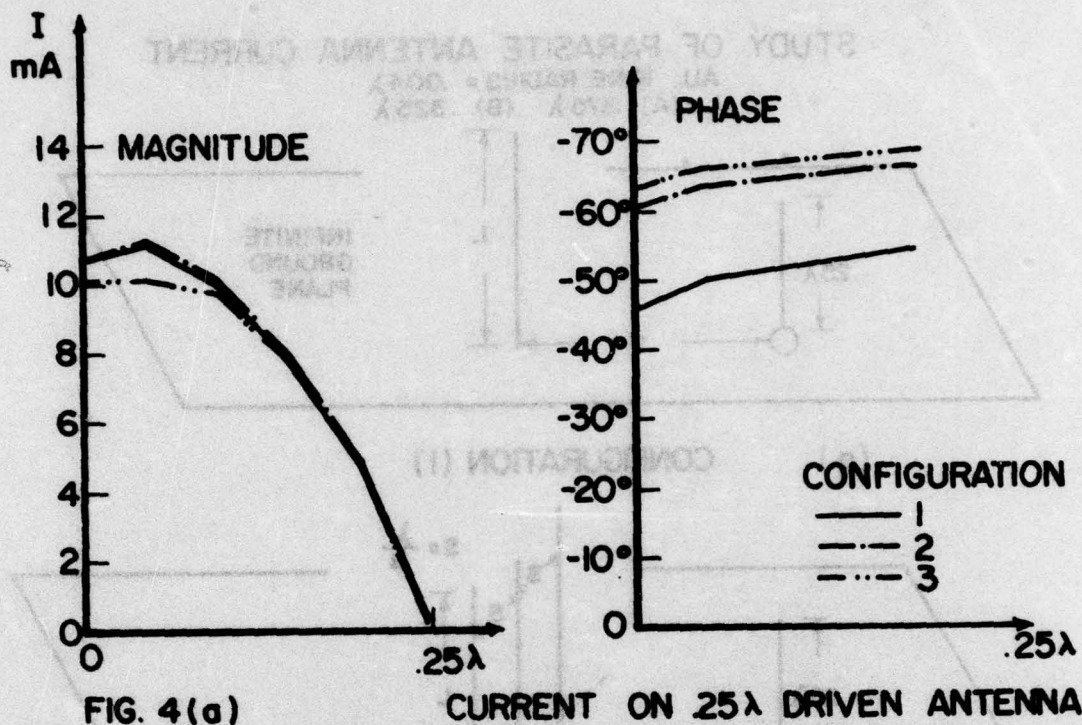


(b) CONFIGURATION (2)



(c) CONFIGURATION (3)

FIG. 3 ADJACENT WIRE COUPLING BY DIFFERENT GEOMETRY



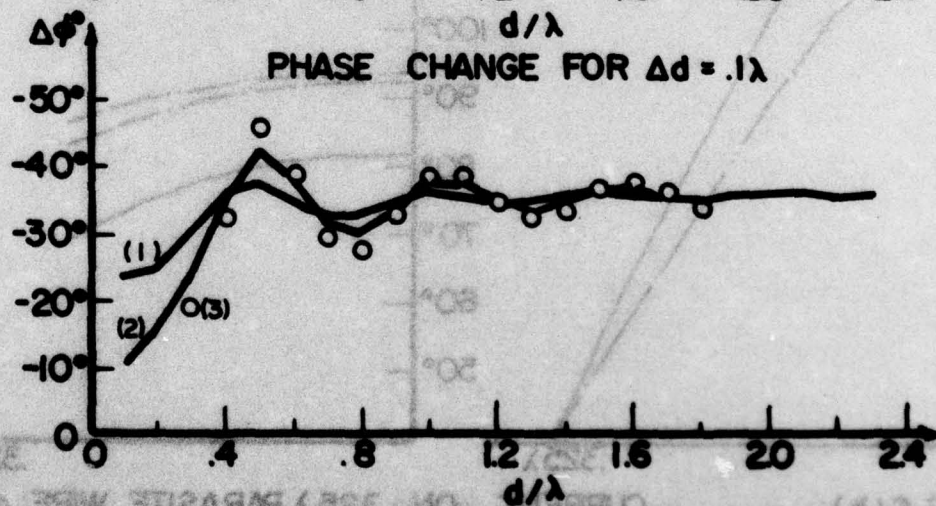
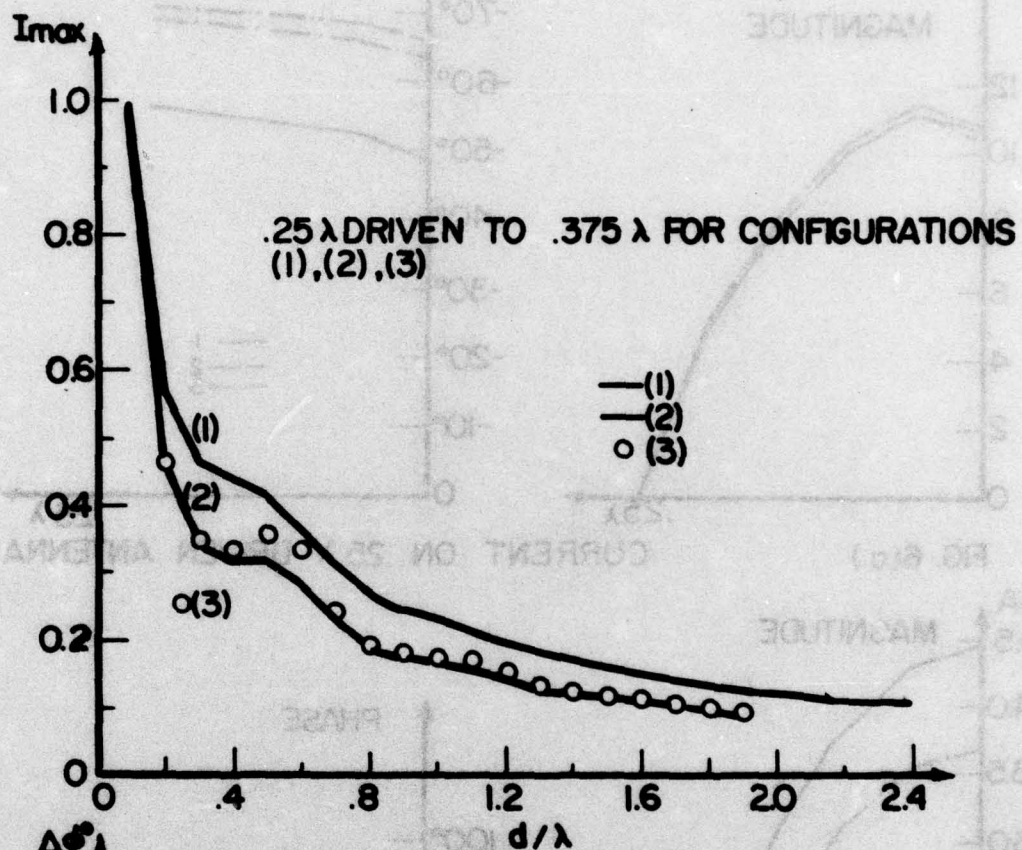
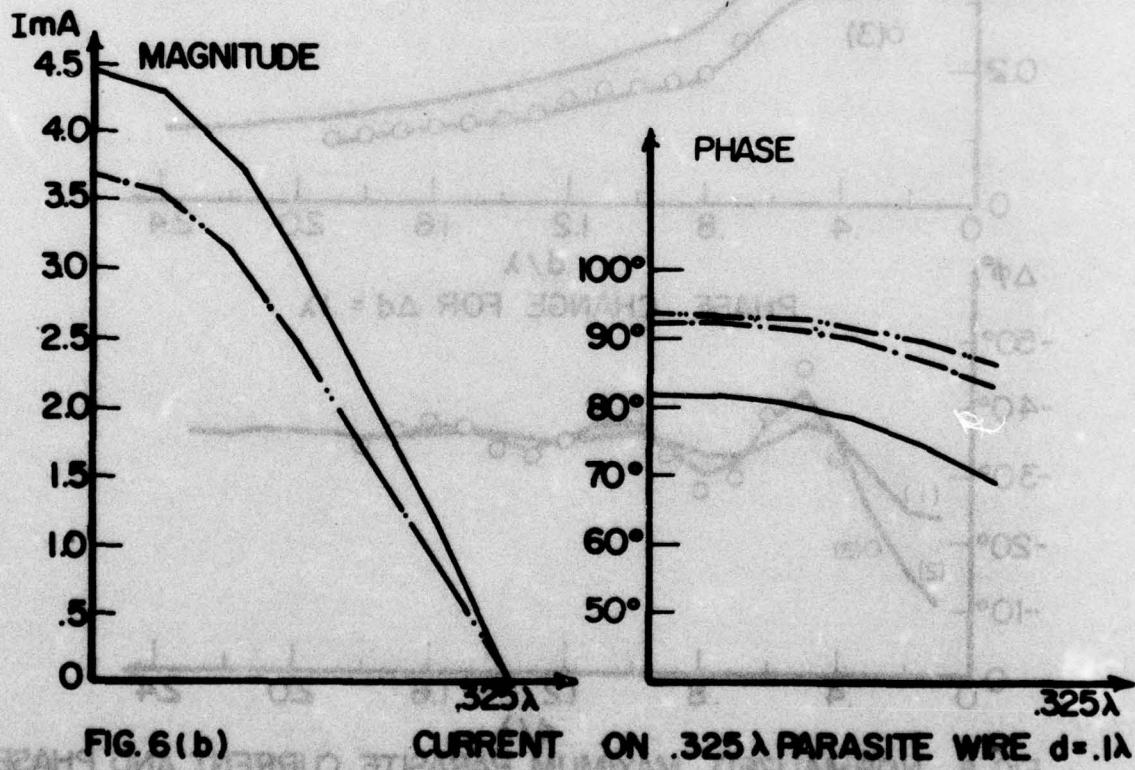
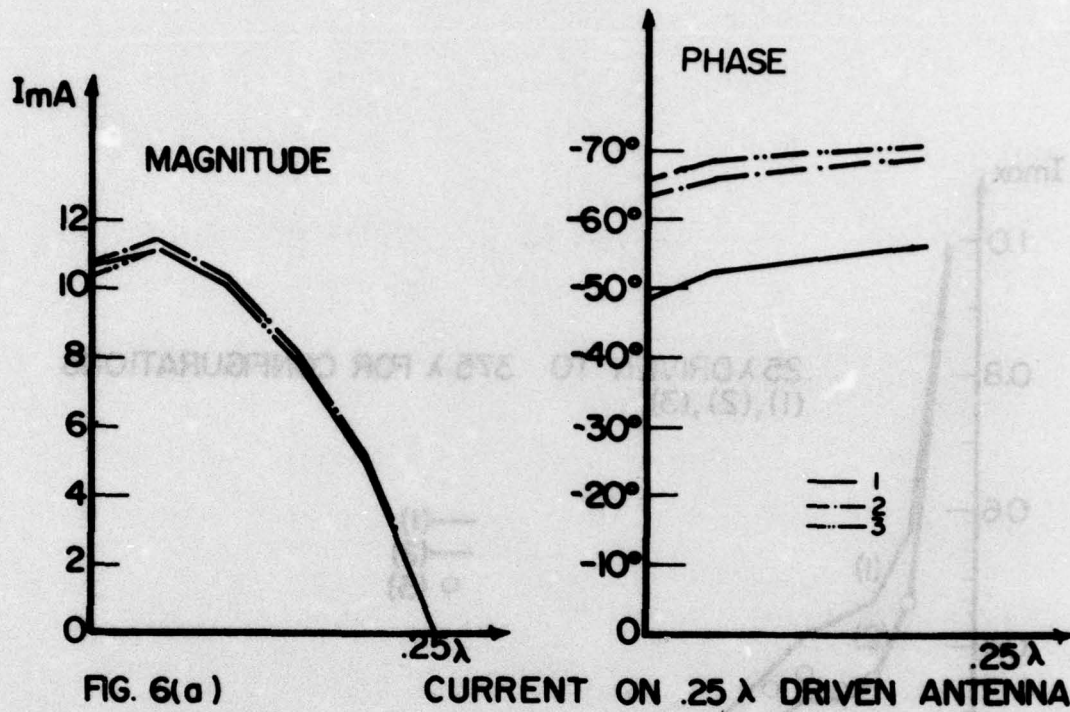
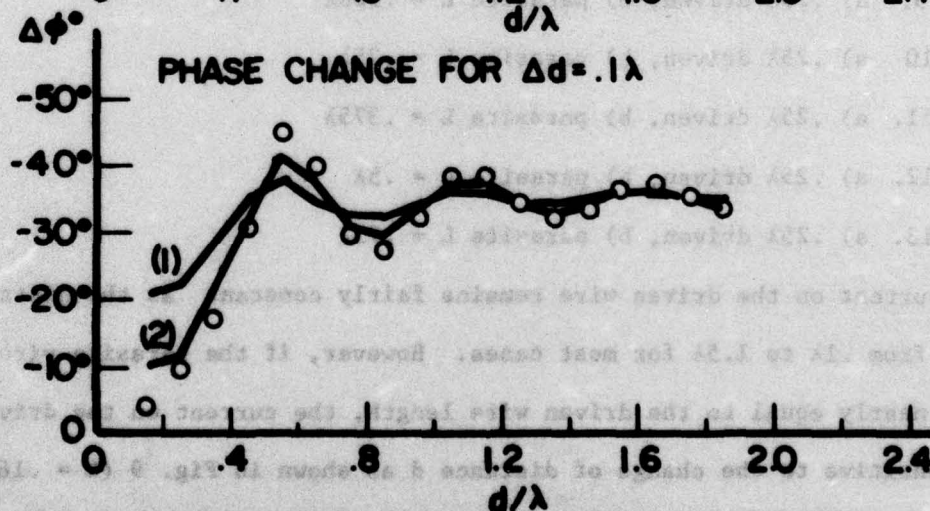
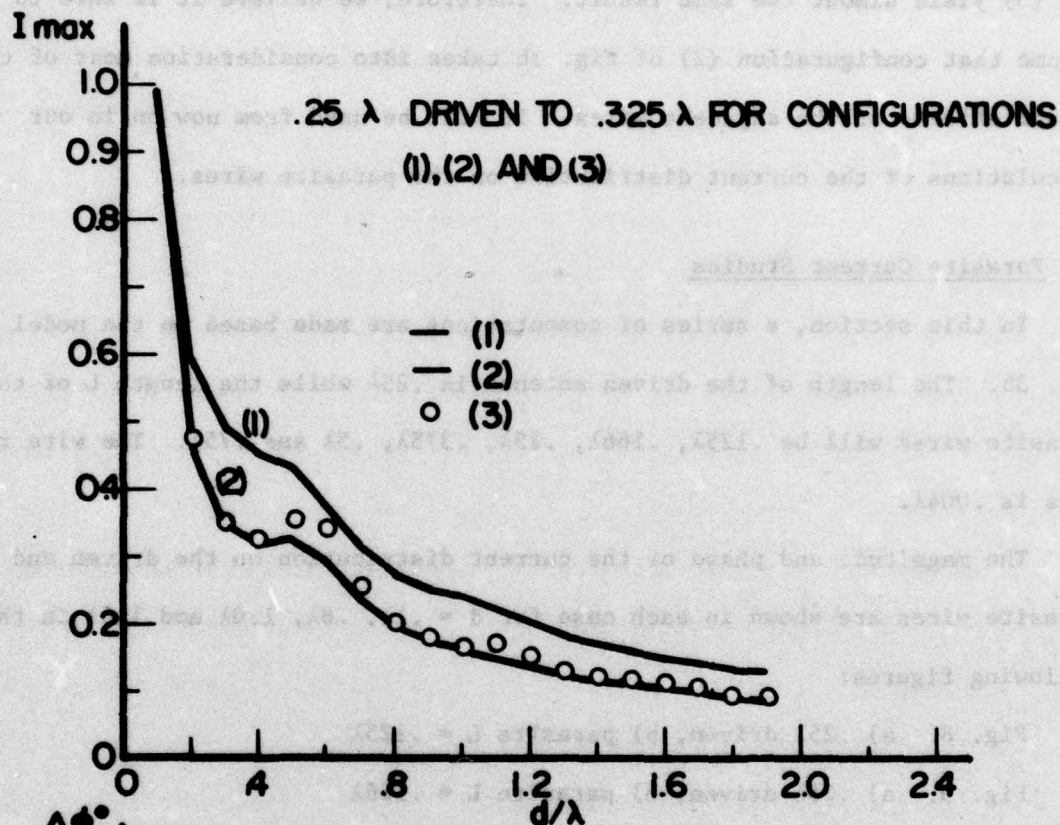


FIG. 5 NORMALIZED MAXIMUM PARASITE CURRENT AND PHASE  
 AS A FUNCTION OF  $d/\lambda$





**FIG. 7 NORMALIZED MAXIMUM PARASITE CURRENT AND PHASE AS A FUNCTION OF  $d/\lambda$**

It is observed from Figs. 4 through Fig. 7 that the configurations (2) and (3) yield almost the same result. Therefore, we believe it is safe to assume that configuration (2) of Fig. 3b takes into consideration most of the mutual effects of the adjacent wires. It will be used from now on in our calculations of the current distribution on the parasite wires.

#### 4. Parasite Current Studies

In this section, a series of computations are made based on the model of Fig. 3b. The length of the driven antenna is  $.25\lambda$  while the length  $L$  of the parasite wires will be  $.125\lambda$ ,  $.166\lambda$ ,  $.25\lambda$ ,  $.375\lambda$ ,  $.5\lambda$  and  $.75\lambda$ . The wire radius is  $.004\lambda$ .

The magnitude and phase of the current distribution on the driven and parasite wires are shown in each case for  $d = .1\lambda$ ,  $.6\lambda$ ,  $1.0\lambda$  and  $1.5\lambda$  in the following figures:

Fig. 8. a)  $.25\lambda$  driven, b) parasite  $L = .125\lambda$

Fig. 9. a)  $.25\lambda$  driven, b) parasite  $L = .166\lambda$

Fig. 10. a)  $.25\lambda$  driven, b) parasite  $L = .25\lambda$

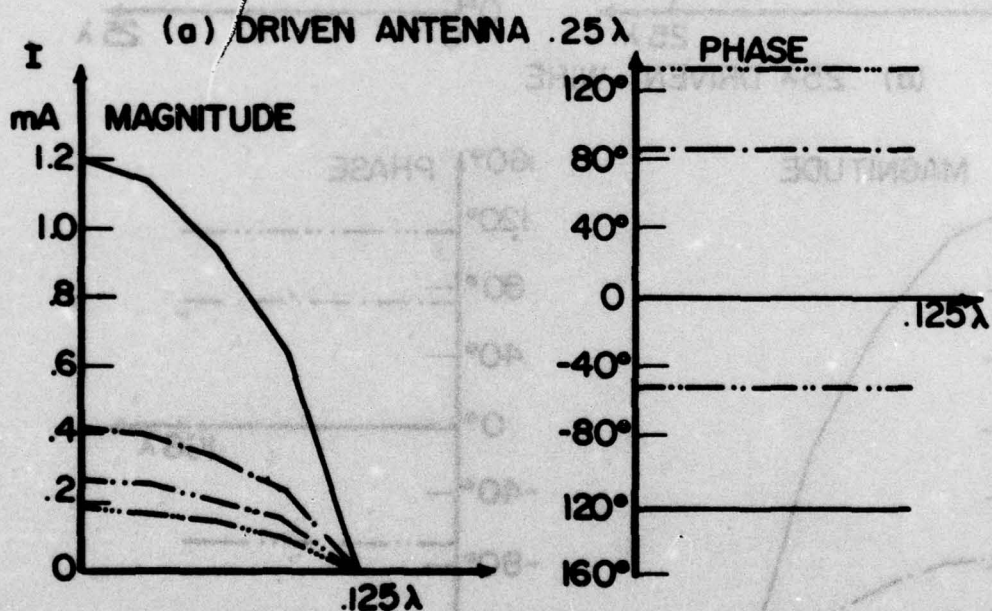
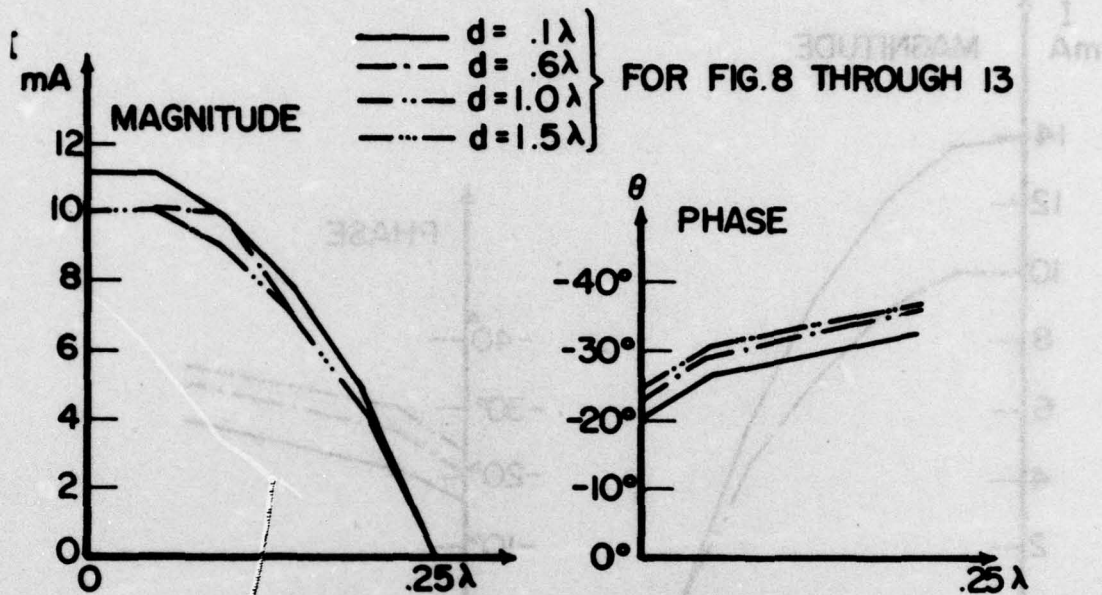
Fig. 11. a)  $.25\lambda$  driven, b) parasite  $L = .375\lambda$

Fig. 12. a)  $.25\lambda$  driven, b) parasite  $L = .5\lambda$

Fig. 13. a)  $.25\lambda$  driven, b) parasite  $L = .75\lambda$

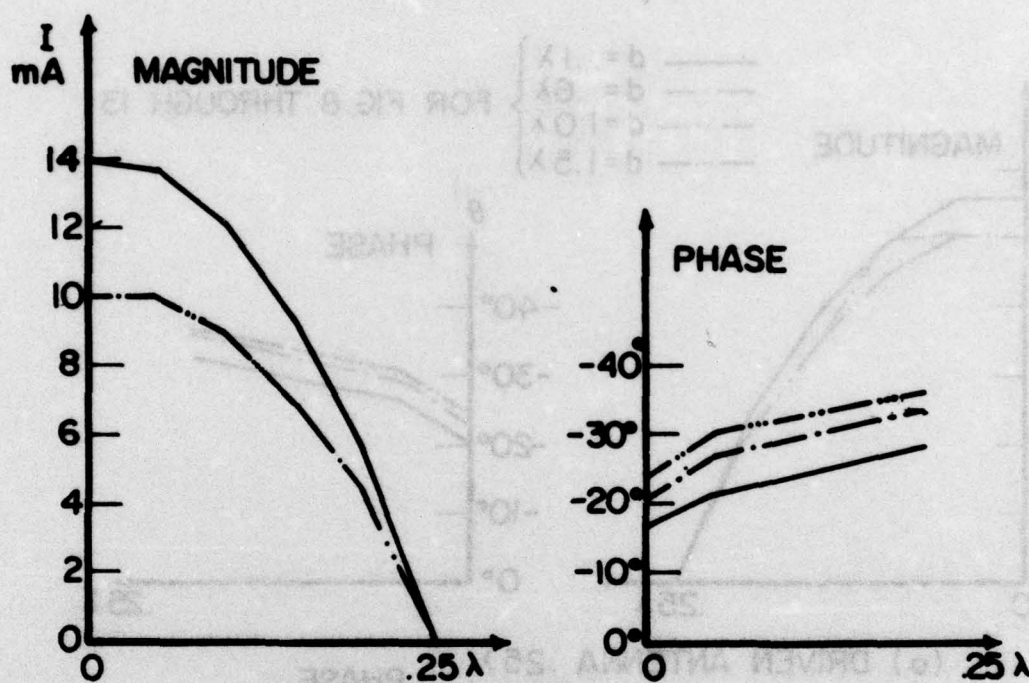
The current on the driven wire remains fairly constant as the distance  $d$  changes from  $.1\lambda$  to  $1.5\lambda$  for most cases. However, if the parasite wire length is nearly equal to the driven wire length, the current on the driven wire is sensitive to the change of distance  $d$  as shown in Fig. 9 ( $L = .166\lambda$ ) and Fig. 10 ( $L = .25\lambda$ ).

The magnitude and phase distribution for the parasite wire current is

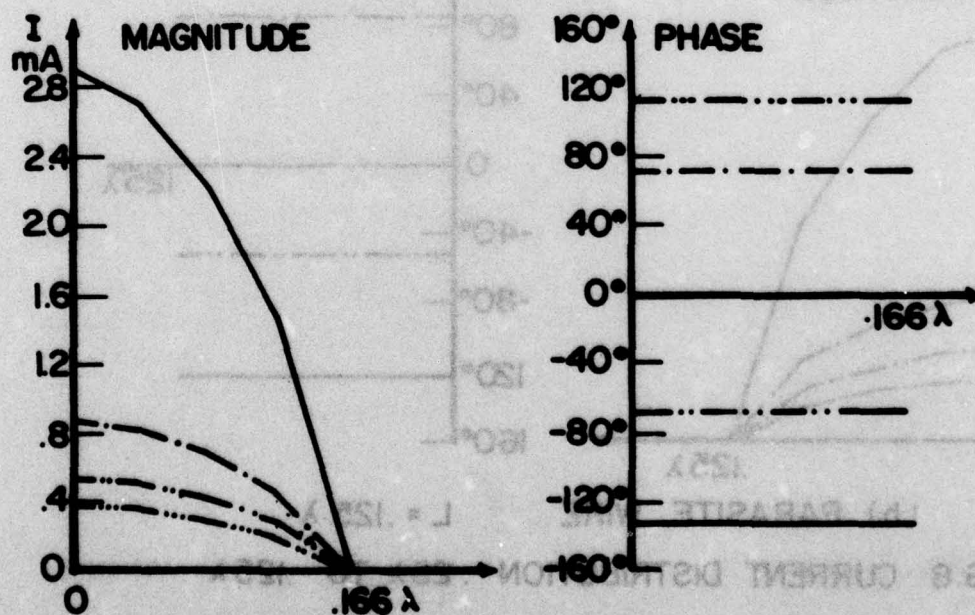


**(b) PARASITE WIRE**  $L = .125\lambda$

**FIG.8 CURRENT DISTRIBUTION .25λ TO .125λ**

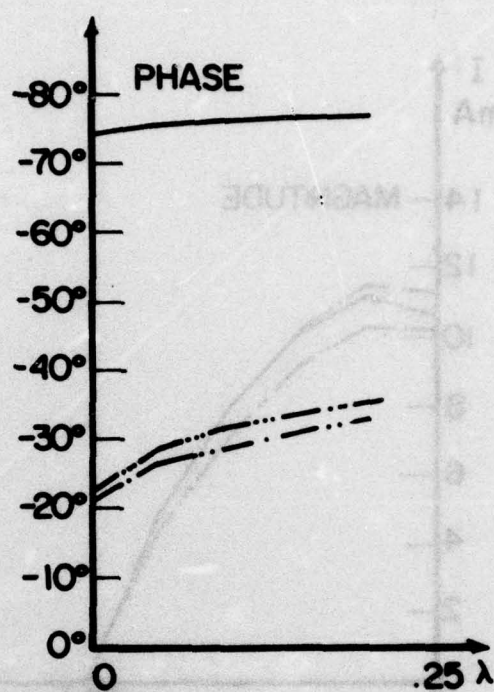
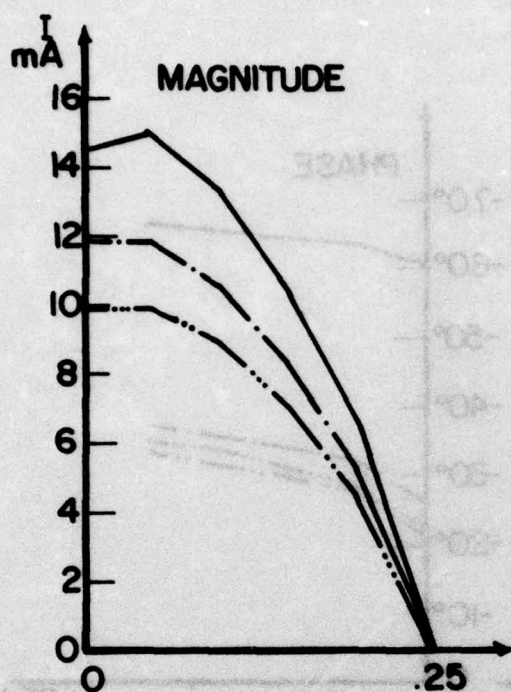


(a)  $.25\lambda$  DRIVEN WIRE

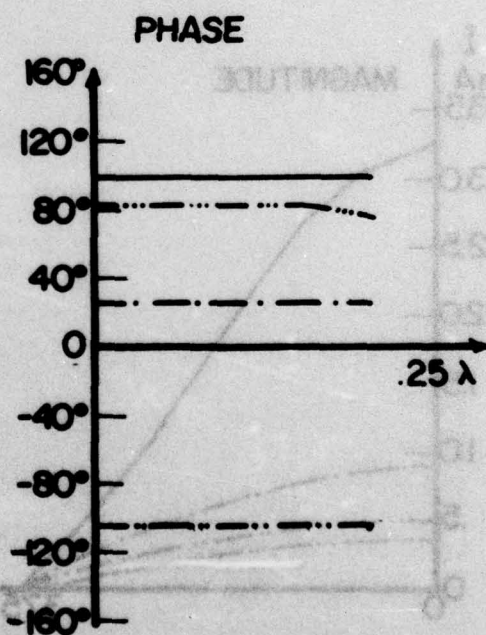
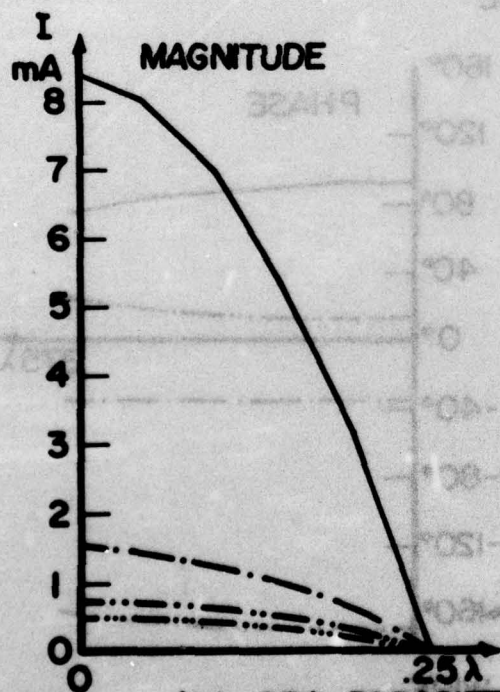


(b)  $.166\lambda$  PARASITE WIRE

FIG. 9 CURRENT DISTRIBUTION  $.25\lambda$  TO  $.166\lambda$



(a)  $.25\lambda$  DRIVEN WIRE



(b)  $.25\lambda$  PARASITE WIRE

FIG. 10 CURRENT DISTRIBUTION  $.25\lambda$  TO  $.25\lambda$

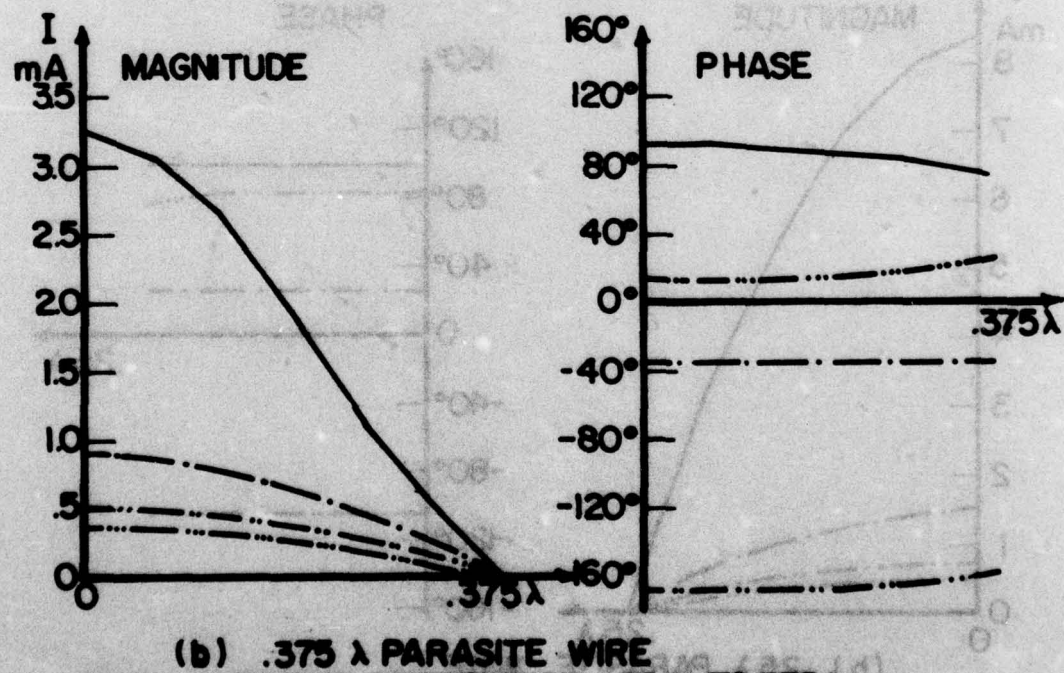
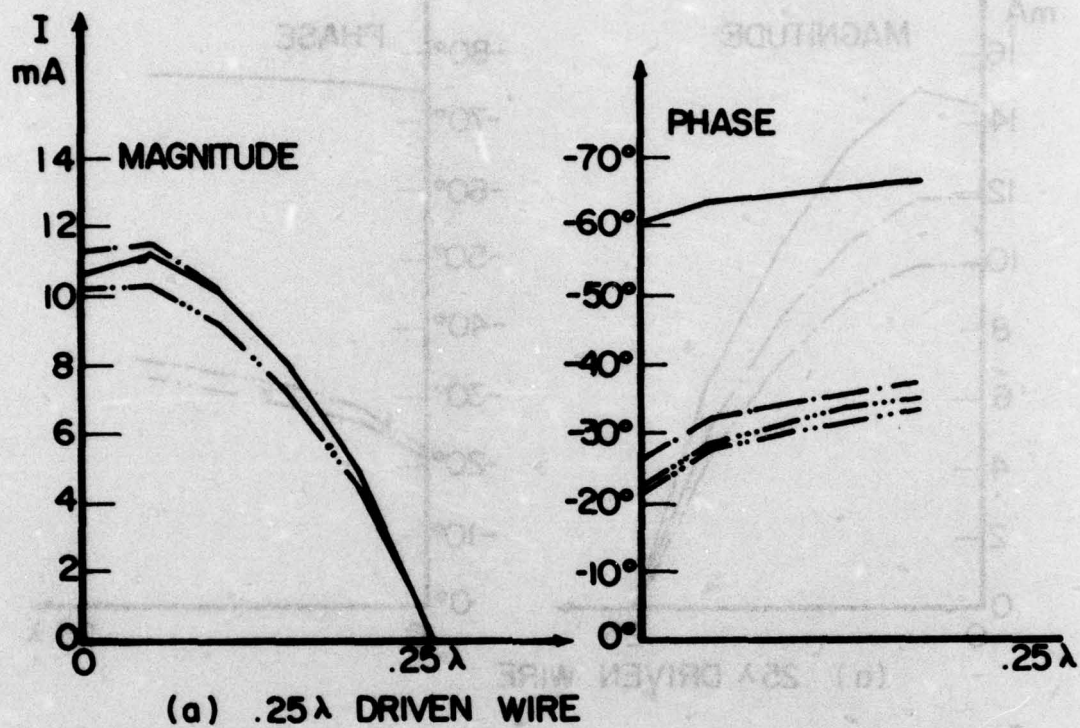


FIG. 11 CURRENT DISTRIBUTION  $.25\lambda$  TO  $.375\lambda$

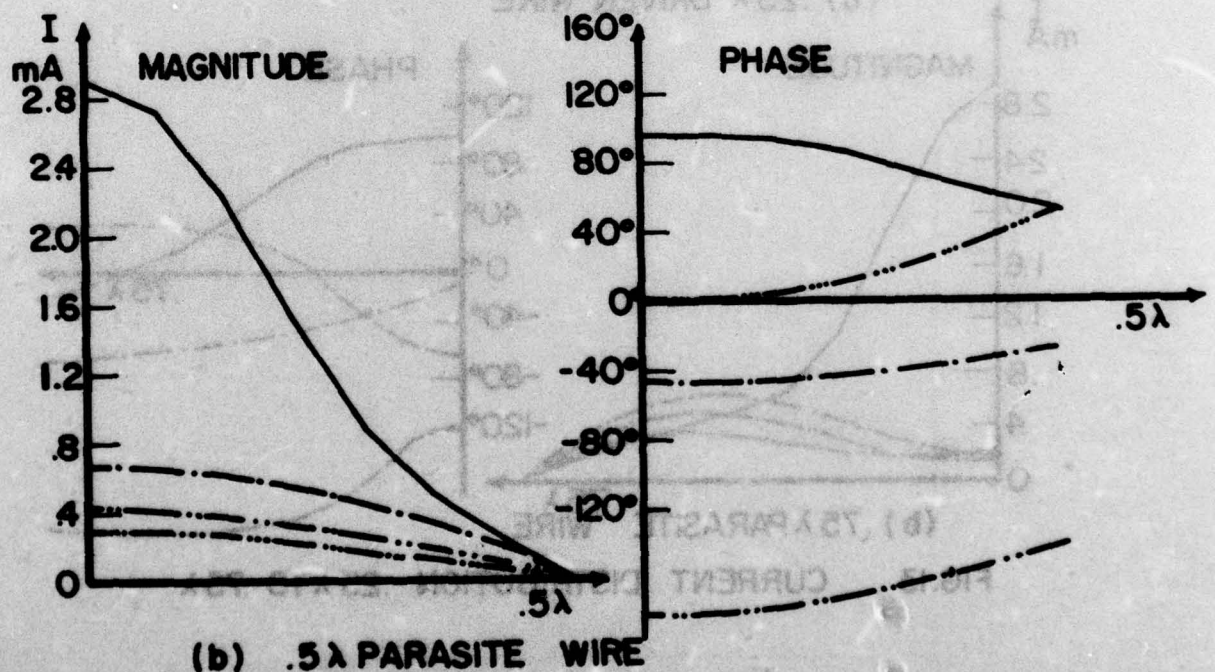
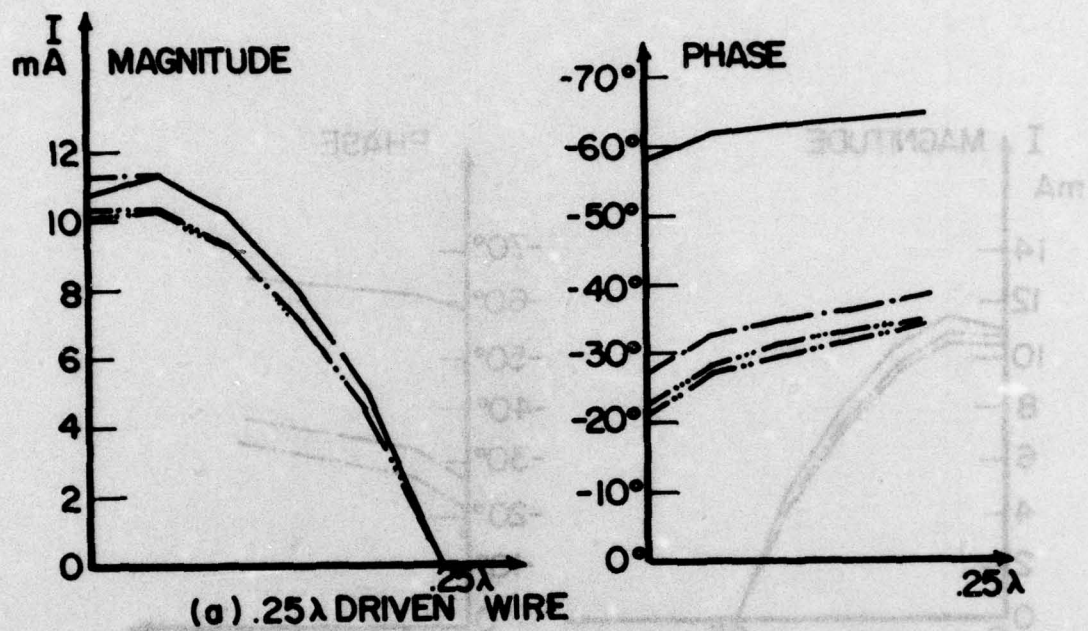


FIG.12 CURRENT DISTRIBUTION  $.25\lambda$  TO  $.5\lambda$

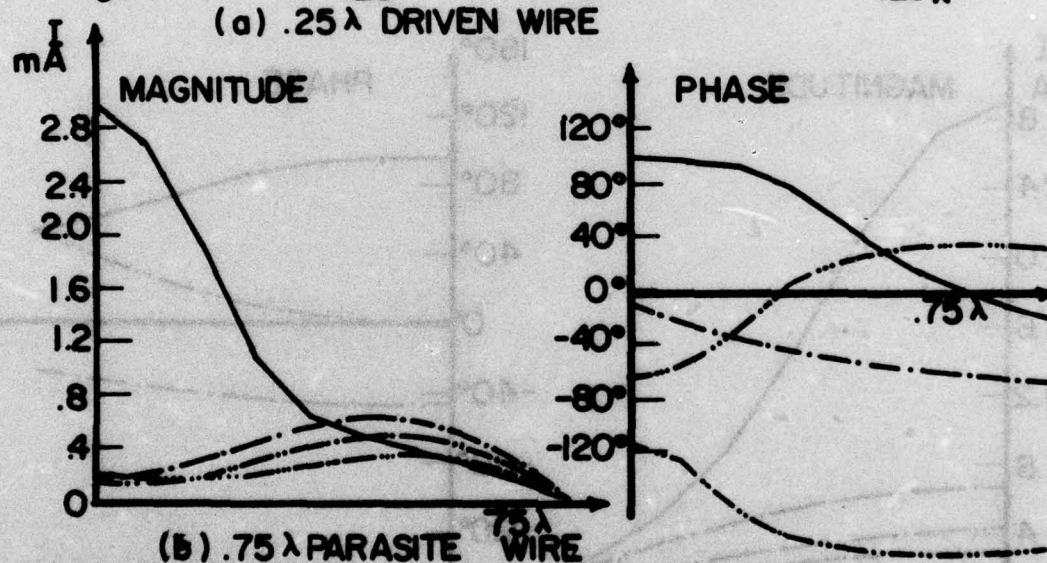
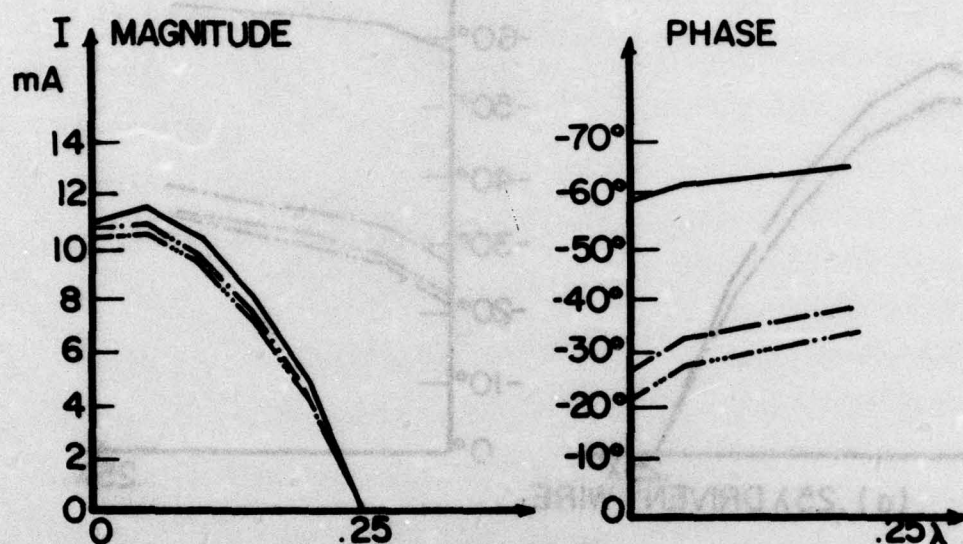


FIG.13 CURRENT DISTRIBUTION  $.25\lambda$  TO  $.75\lambda$

quite regular for all lengths,  $L \leq .5\lambda$ .

The normalized maximum parasite currents as a function of  $d$  for  $L = .125\lambda$ ,  $.166\lambda$ ,  $.25\lambda$ ,  $.375\lambda$ , and  $.5\lambda$  are summarized in Fig. 14 with  $d$  changing from  $.1\lambda$  to  $2.0\lambda$ . From this plot it is seen that the change in the current magnitude with  $d$  closely resembles  $K/d$  as shown in Fig. 15, if the proper value of  $K$  is selected. The phase change for the steps  $\Delta d = .1\lambda$  is nearly constant and equal to  $36^\circ$  for  $d > .5\lambda$ . Even for values of  $d$  smaller than  $.5\lambda$  the deviation is quite acceptable for radiation pattern purposes.

After some experimenting, we found that, for  $L$  in the range of values studied, for  $d \geq .8\lambda$  the magnitude and phase of the parasite current distribution are uniform and inversely proportional to  $d$ . We can relate the currents for  $d \geq .8\lambda$  to their computed value at  $d = .8\lambda$  by the following simple relations.

$$\begin{aligned} |I|(d) &= \frac{K}{(d/\lambda)} \\ \theta(d) &= \frac{2\pi}{\lambda} (d - .8\lambda) + \theta(.8\lambda) \end{aligned} \tag{1}$$

where  $K$  is a constant to be determined from

$$\frac{K}{.8} = |I|(.8\lambda)$$

where  $|I|(.8\lambda)$  is the current magnitude at  $d = .8\lambda$

$\theta(.8\lambda)$  is phase of the current at  $d = .8\lambda$ .

As an example for  $L = .125\lambda$ ,  $K = 2.24$  and Fig. 16 shows in the solid line a plot of curve (1) of Fig. 14 and in the X's, the computed values for  $|I|(d) = 2.24/(d/\lambda)$ . The agreement is very good indeed. Similar results are obtained for the other values of  $L$ . The representation is especially good for  $d \geq .8\lambda$ .

##### 5. Equivalent Point Source

The parasite wire current can be obtained for any value of  $d$  by using MOM

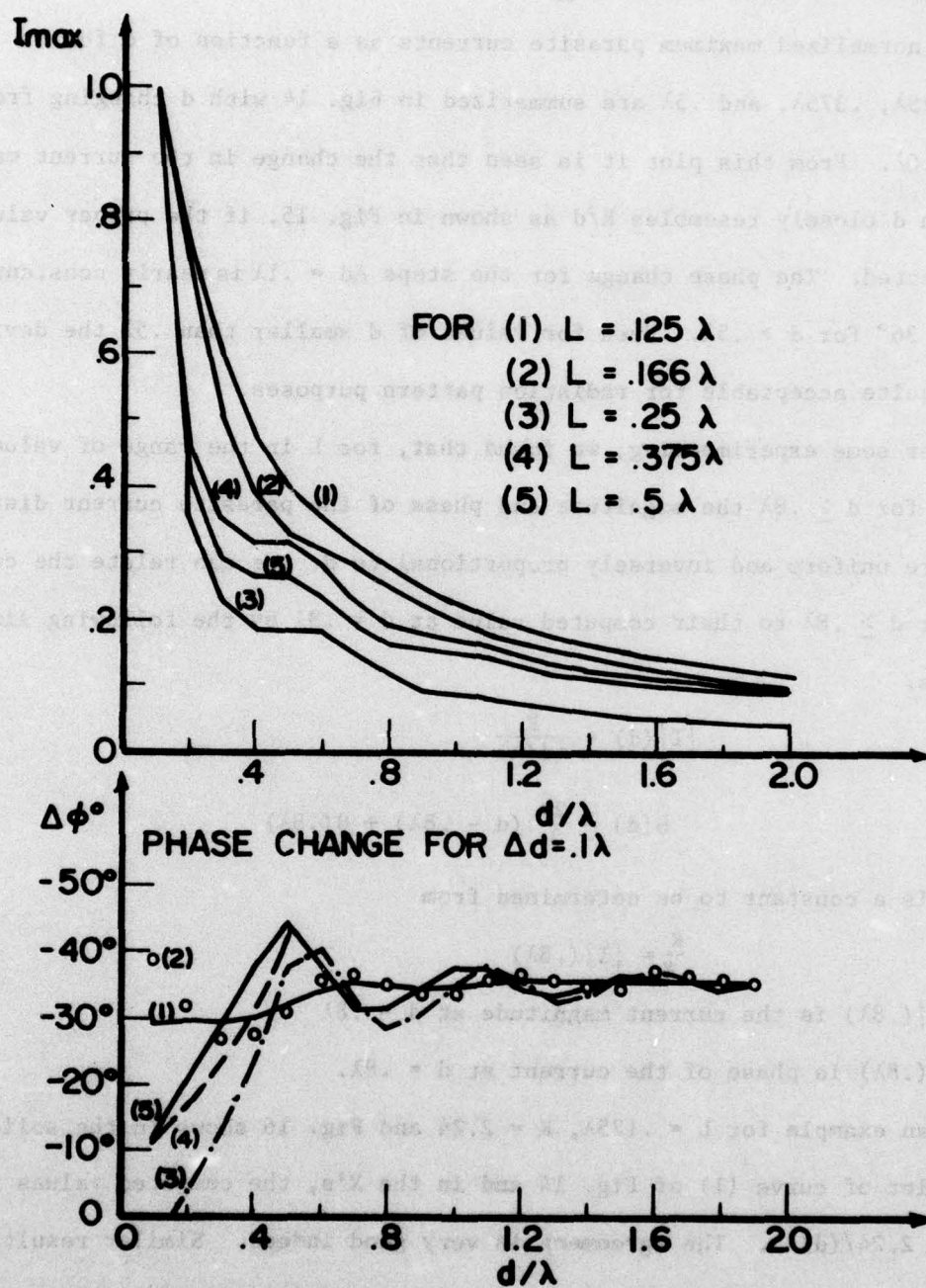


FIG. 14 NORMALIZED MAXIMUM PARASITE CURRENT AND PHASE AS A FUNCTION OF  $d/\lambda$

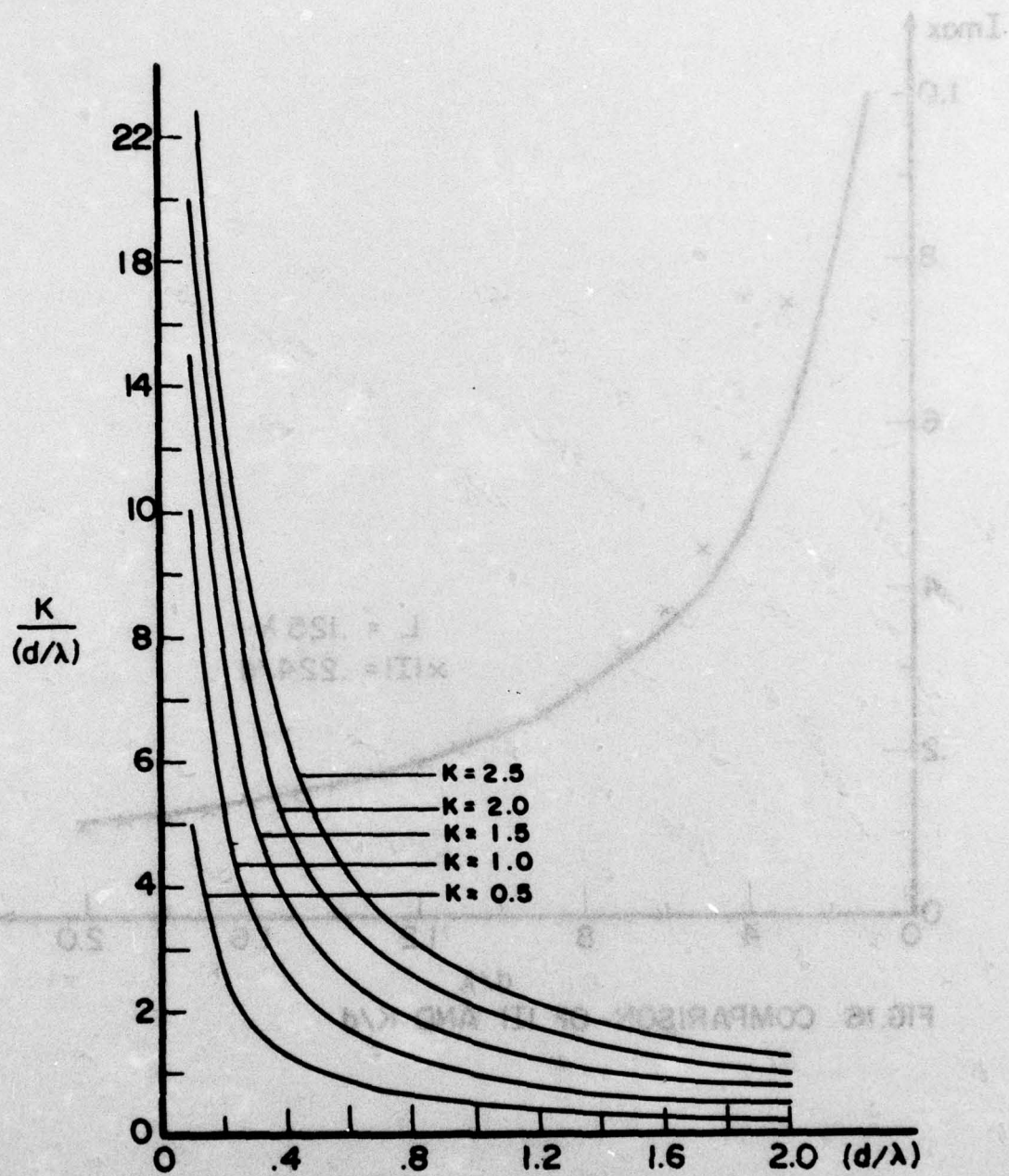


FIG. 15 THE VARIOUS CURVES OF  $K/d$

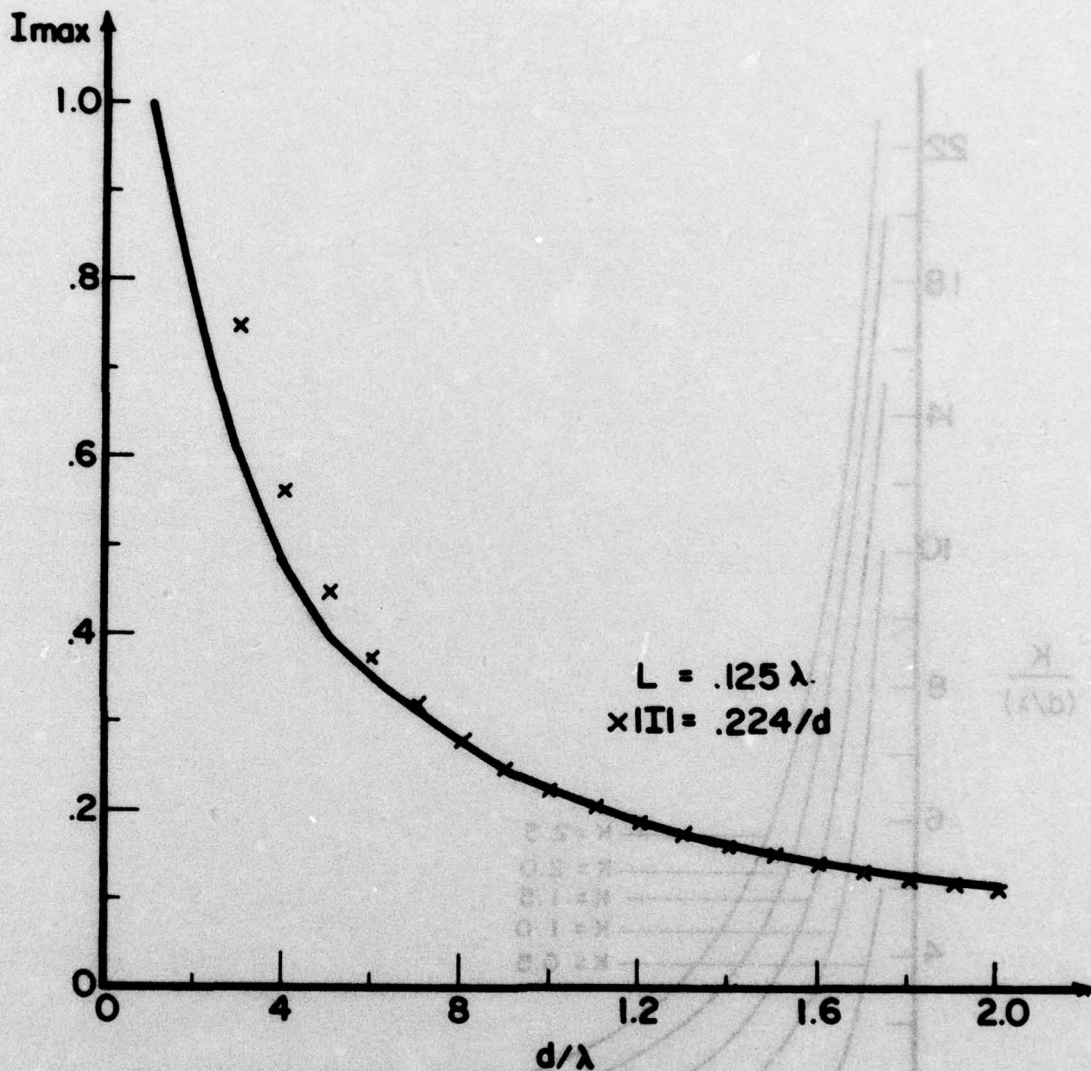


FIG.16 COMPARISON OF  $|I|$  AND  $K/d$

once for  $d = .8\lambda$  and equations (1). After the current is obtained for every parasite wire of Fig. 2, each wire can be treated as a point source  $I_p$  by summing the phasor contribution of each current element in the desired angle as shown in Fig. 17 by the equation

$$I_p = \sum_{i=0}^N I_i e^{j\left(\frac{2\pi l_i \sin\theta}{\lambda} + \theta_i\right)}$$

After all equivalent point sources have been obtained, the problem of Fig. 2 can be treated by the synthesis program referred to in section 1 [1] as a planar array of point sources.

#### 6. Conclusions and Recommendations.

It seems that the hypotheses set forth in the introduction of this report have been satisfactorily verified. Before we proceed and apply these results to the problem of optimizing the antenna site on ships, we would like to verify further the hypothesis set forth by Raschke and Sterling [2] and stated in section 2 of this report. The computations made by them referred to infinitely long cylinders. We would like to use the body of revolution computer program [4] and MOM program to check the same hypothesis for finite size cylinders. The influence of the wire separation  $S$ , the number of wires, and wire radius can be very easily studied with the use of these codes.

#### References

- [1] Perini, J., Idselis, M.M., "Point Source Radiation Pattern Synthesis by Iterative Techniques," NAVY Report (to be published).
- [2] Raschke, R.R., Sterling, J.T., Final Engineering Report: Linear Antenna Pattern Prediction Model Development, Contract N00024-73C-1277, Space Systems, General Electric Co., Daytona Beach, Florida.

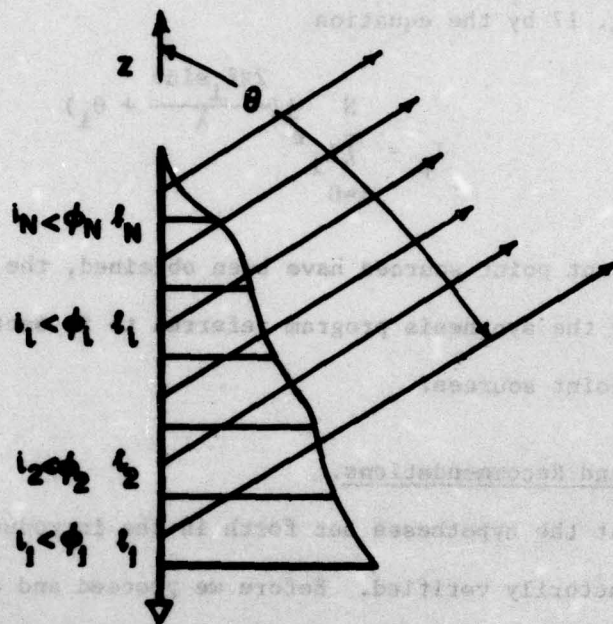


FIG 17 EQUIVALENT POINT SOURCE

- References
- [1] Bayard, J., "Point Source Radiation Pattern Synthesis by Iterative Techniques," NAVY Report (to be published).
  - [2] Rasmussen, R.R., Stearling, J.T., "Final Engineering Report: Linear Antenna Pattern Radiation Model Development, Contract N00039-73C-157, Space Systems, General Electric Co., Dayton, Ohio, 1974.

[3] Perini, J., Internal letter to Raschke.

[4] Mautz, J.R., Harrington, R.F., "Radiation and Scattering from Bodies of Revolution," App. Sci. Res., Vol. 20, June 1969.

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PRIMARY UNITS		DERIVATIVE UNITS	
Symbol	Unit	Symbol	Unit
m	meter	m/s	meter per second
kg	kilogram	m/s <sup>2</sup>	meter per second squared
s	second	m <sup>2</sup> /s	square meter per second
A	ampere	m <sup>3</sup> /s	cubic meter per second
V	volt	m <sup>2</sup> /s <sup>2</sup>	square meter per second squared
W	watt	m <sup>3</sup> /s <sup>2</sup>	cubic meter per second squared
J	joule	m <sup>4</sup> /s <sup>2</sup>	fourth power of meter per second squared
N	newton	m <sup>5</sup> /s <sup>2</sup>	fifth power of meter per second squared
Pa	pascal	m <sup>6</sup> /s <sup>2</sup>	sixth power of meter per second squared
Wb	weber	m <sup>7</sup> /s <sup>2</sup>	seventh power of meter per second squared
T	tesla	m <sup>8</sup> /s <sup>2</sup>	eighth power of meter per second squared
C	coulomb	m <sup>9</sup> /s <sup>2</sup>	ninth power of meter per second squared
F	farad	m <sup>10</sup> /s <sup>2</sup>	tenth power of meter per second squared
H	henry	m <sup>11</sup> /s <sup>2</sup>	eleventh power of meter per second squared
Wb/V	weber per volt	m <sup>12</sup> /s <sup>2</sup>	twelfth power of meter per second squared
Wb/A	weber per ampere	m <sup>13</sup> /s <sup>2</sup>	thirteenth power of meter per second squared
Wb/m	weber per meter	m <sup>14</sup> /s <sup>2</sup>	fourteenth power of meter per second squared
Wb/m <sup>2</sup>	weber per square meter	m <sup>15</sup> /s <sup>2</sup>	fifteenth power of meter per second squared
Wb/m <sup>3</sup>	weber per cubic meter	m <sup>16</sup> /s <sup>2</sup>	sixteenth power of meter per second squared
Wb/m <sup>4</sup>	weber per fourth power of meter	m <sup>17</sup> /s <sup>2</sup>	seventeenth power of meter per second squared
Wb/m <sup>5</sup>	weber per fifth power of meter	m <sup>18</sup> /s <sup>2</sup>	eighteenth power of meter per second squared
Wb/m <sup>6</sup>	weber per sixth power of meter	m <sup>19</sup> /s <sup>2</sup>	nineteenth power of meter per second squared
Wb/m <sup>7</sup>	weber per seventh power of meter	m <sup>20</sup> /s <sup>2</sup>	twentieth power of meter per second squared
Wb/m <sup>8</sup>	weber per eighth power of meter	m <sup>21</sup> /s <sup>2</sup>	twenty-first power of meter per second squared
Wb/m <sup>9</sup>	weber per ninth power of meter	m <sup>22</sup> /s <sup>2</sup>	twenty-second power of meter per second squared
Wb/m <sup>10</sup>	weber per tenth power of meter	m <sup>23</sup> /s <sup>2</sup>	twenty-third power of meter per second squared
Wb/m <sup>11</sup>	weber per eleventh power of meter	m <sup>24</sup> /s <sup>2</sup>	twenty-fourth power of meter per second squared
Wb/m <sup>12</sup>	weber per twelfth power of meter	m <sup>25</sup> /s <sup>2</sup>	twenty-fifth power of meter per second squared
Wb/m <sup>13</sup>	weber per thirteenth power of meter	m <sup>26</sup> /s <sup>2</sup>	twenty-sixth power of meter per second squared
Wb/m <sup>14</sup>	weber per fourteenth power of meter	m <sup>27</sup> /s <sup>2</sup>	twenty-seventh power of meter per second squared
Wb/m <sup>15</sup>	weber per fifteenth power of meter	m <sup>28</sup> /s <sup>2</sup>	twenty-eighth power of meter per second squared
Wb/m <sup>16</sup>	weber per sixteenth power of meter	m <sup>29</sup> /s <sup>2</sup>	twenty-ninth power of meter per second squared
Wb/m <sup>17</sup>	weber per seventeenth power of meter	m <sup>30</sup> /s <sup>2</sup>	thirtieth power of meter per second squared
Wb/m <sup>18</sup>	weber per eighteenth power of meter	m <sup>31</sup> /s <sup>2</sup>	thirty-first power of meter per second squared
Wb/m <sup>19</sup>	weber per nineteenth power of meter	m <sup>32</sup> /s <sup>2</sup>	thirty-second power of meter per second squared
Wb/m <sup>20</sup>	weber per twentieth power of meter	m <sup>33</sup> /s <sup>2</sup>	thirty-third power of meter per second squared
Wb/m <sup>21</sup>	weber per twenty-first power of meter	m <sup>34</sup> /s <sup>2</sup>	thirty-fourth power of meter per second squared
Wb/m <sup>22</sup>	weber per twenty-second power of meter	m <sup>35</sup> /s <sup>2</sup>	thirty-fifth power of meter per second squared
Wb/m <sup>23</sup>	weber per twenty-third power of meter	m <sup>36</sup> /s <sup>2</sup>	thirty-sixth power of meter per second squared
Wb/m <sup>24</sup>	weber per twenty-fourth power of meter	m <sup>37</sup> /s <sup>2</sup>	thirty-seventh power of meter per second squared
Wb/m <sup>25</sup>	weber per twenty-fifth power of meter	m <sup>38</sup> /s <sup>2</sup>	thirty-eighth power of meter per second squared
Wb/m <sup>26</sup>	weber per twenty-sixth power of meter	m <sup>39</sup> /s <sup>2</sup>	thirty-ninth power of meter per second squared
Wb/m <sup>27</sup>	weber per twenty-seventh power of meter	m <sup>40</sup> /s <sup>2</sup>	fortieth power of meter per second squared
Wb/m <sup>28</sup>	weber per twenty-eighth power of meter	m <sup>41</sup> /s <sup>2</sup>	forty-first power of meter per second squared
Wb/m <sup>29</sup>	weber per twenty-ninth power of meter	m <sup>42</sup> /s <sup>2</sup>	forty-second power of meter per second squared
Wb/m <sup>30</sup>	weber per thirtieth power of meter	m <sup>43</sup> /s <sup>2</sup>	forty-third power of meter per second squared
Wb/m <sup>31</sup>	weber per thirty-first power of meter	m <sup>44</sup> /s <sup>2</sup>	forty-fourth power of meter per second squared
Wb/m <sup>32</sup>	weber per thirty-second power of meter	m <sup>45</sup> /s <sup>2</sup>	forty-fifth power of meter per second squared
Wb/m <sup>33</sup>	weber per thirty-third power of meter	m <sup>46</sup> /s <sup>2</sup>	forty-sixth power of meter per second squared
Wb/m <sup>34</sup>	weber per thirty-fourth power of meter	m <sup>47</sup> /s <sup>2</sup>	forty-seventh power of meter per second squared
Wb/m <sup>35</sup>	weber per thirty-fifth power of meter	m <sup>48</sup> /s <sup>2</sup>	forty-eighth power of meter per second squared
Wb/m <sup>36</sup>	weber per thirty-sixth power of meter	m <sup>49</sup> /s <sup>2</sup>	forty-ninth power of meter per second squared
Wb/m <sup>37</sup>	weber per thirty-seventh power of meter	m <sup>50</sup> /s <sup>2</sup>	fiftieth power of meter per second squared
Wb/m <sup>38</sup>	weber per thirty-eighth power of meter	m <sup>51</sup> /s <sup>2</sup>	fifty-first power of meter per second squared
Wb/m <sup>39</sup>	weber per thirty-ninth power of meter	m <sup>52</sup> /s <sup>2</sup>	fifty-second power of meter per second squared
Wb/m <sup>40</sup>	weber per fortieth power of meter	m <sup>53</sup> /s <sup>2</sup>	fifty-third power of meter per second squared
Wb/m <sup>41</sup>	weber per forty-first power of meter	m <sup>54</sup> /s <sup>2</sup>	fifty-fourth power of meter per second squared
Wb/m <sup>42</sup>	weber per forty-second power of meter	m <sup>55</sup> /s <sup>2</sup>	fifty-fifth power of meter per second squared
Wb/m <sup>43</sup>	weber per forty-third power of meter	m <sup>56</sup> /s <sup>2</sup>	fifty-sixth power of meter per second squared
Wb/m <sup>44</sup>	weber per forty-fourth power of meter	m <sup>57</sup> /s <sup>2</sup>	fifty-seventh power of meter per second squared
Wb/m <sup>45</sup>	weber per forty-fifth power of meter	m <sup>58</sup> /s <sup>2</sup>	fifty-eighth power of meter per second squared
Wb/m <sup>46</sup>	weber per forty-sixth power of meter	m <sup>59</sup> /s <sup>2</sup>	fifty-ninth power of meter per second squared
Wb/m <sup>47</sup>	weber per forty-seventh power of meter	m <sup>60</sup> /s <sup>2</sup>	sixtieth power of meter per second squared
Wb/m <sup>48</sup>	weber per forty-eighth power of meter	m <sup>61</sup> /s <sup>2</sup>	sixty-first power of meter per second squared
Wb/m <sup>49</sup>	weber per forty-ninth power of meter	m <sup>62</sup> /s <sup>2</sup>	sixty-second power of meter per second squared
Wb/m <sup>50</sup>	weber per fiftieth power of meter	m <sup>63</sup> /s <sup>2</sup>	sixty-third power of meter per second squared
Wb/m <sup>51</sup>	weber per fifty-first power of meter	m <sup>64</sup> /s <sup>2</sup>	sixty-fourth power of meter per second squared
Wb/m <sup>52</sup>	weber per fifty-second power of meter	m <sup>65</sup> /s <sup>2</sup>	sixty-fifth power of meter per second squared
Wb/m <sup>53</sup>	weber per fifty-third power of meter	m <sup>66</sup> /s <sup>2</sup>	sixty-sixth power of meter per second squared
Wb/m <sup>54</sup>	weber per fifty-fourth power of meter	m <sup>67</sup> /s <sup>2</sup>	sixty-seventh power of meter per second squared
Wb/m <sup>55</sup>	weber per fifty-fifth power of meter	m <sup>68</sup> /s <sup>2</sup>	sixty-eighth power of meter per second squared
Wb/m <sup>56</sup>	weber per fifty-sixth power of meter	m <sup>69</sup> /s <sup>2</sup>	sixty-ninth power of meter per second squared
Wb/m <sup>57</sup>	weber per fifty-seventh power of meter	m <sup>70</sup> /s <sup>2</sup>	seventieth power of meter per second squared
Wb/m <sup>58</sup>	weber per fifty-eighth power of meter	m <sup>71</sup> /s <sup>2</sup>	seventy-first power of meter per second squared
Wb/m <sup>59</sup>	weber per fifty-ninth power of meter	m <sup>72</sup> /s <sup>2</sup>	seventy-second power of meter per second squared
Wb/m <sup>60</sup>	weber per sixtieth power of meter	m <sup>73</sup> /s <sup>2</sup>	seventy-third power of meter per second squared
Wb/m <sup>61</sup>	weber per sixty-first power of meter	m <sup>74</sup> /s <sup>2</sup>	seventy-fourth power of meter per second squared
Wb/m <sup>62</sup>	weber per sixty-second power of meter	m <sup>75</sup> /s <sup>2</sup>	seventy-fifth power of meter per second squared
Wb/m <sup>63</sup>	weber per sixty-third power of meter	m <sup>76</sup> /s <sup>2</sup>	seventy-sixth power of meter per second squared
Wb/m <sup>64</sup>	weber per sixty-fourth power of meter	m <sup>77</sup> /s <sup>2</sup>	seventy-seventh power of meter per second squared
Wb/m <sup>65</sup>	weber per sixty-fifth power of meter	m <sup>78</sup> /s <sup>2</sup>	seventy-eighth power of meter per second squared
Wb/m <sup>66</sup>	weber per sixty-sixth power of meter	m <sup>79</sup> /s <sup>2</sup>	seventy-ninth power of meter per second squared
Wb/m <sup>67</sup>	weber per sixty-seventh power of meter	m <sup>80</sup> /s <sup>2</sup>	eightieth power of meter per second squared
Wb/m <sup>68</sup>	weber per sixty-eighth power of meter	m <sup>81</sup> /s <sup>2</sup>	eighty-first power of meter per second squared
Wb/m <sup>69</sup>	weber per sixty-ninth power of meter	m <sup>82</sup> /s <sup>2</sup>	eighty-second power of meter per second squared
Wb/m <sup>70</sup>	weber per seventieth power of meter	m <sup>83</sup> /s <sup>2</sup>	eighty-third power of meter per second squared
Wb/m <sup>71</sup>	weber per seventy-first power of meter	m <sup>84</sup> /s <sup>2</sup>	eighty-fourth power of meter per second squared
Wb/m <sup>72</sup>	weber per seventy-second power of meter	m <sup>85</sup> /s <sup>2</sup>	eighty-fifth power of meter per second squared
Wb/m <sup>73</sup>	weber per seventy-third power of meter	m <sup>86</sup> /s <sup>2</sup>	eighty-sixth power of meter per second squared
Wb/m <sup>74</sup>	weber per seventy-fourth power of meter	m <sup>87</sup> /s <sup>2</sup>	eighty-seventh power of meter per second squared
Wb/m <sup>75</sup>	weber per seventy-fifth power of meter	m <sup>88</sup> /s <sup>2</sup>	eighty-eighth power of meter per second squared
Wb/m <sup>76</sup>	weber per seventy-sixth power of meter	m <sup>89</sup> /s <sup>2</sup>	eighty-ninth power of meter per second squared
Wb/m <sup>77</sup>	weber per seventy-seventh power of meter	m <sup>90</sup> /s <sup>2</sup>	ninetieth power of meter per second squared
Wb/m <sup>78</sup>	weber per seventy-eighth power of meter	m <sup>91</sup> /s <sup>2</sup>	ninety-first power of meter per second squared
Wb/m <sup>79</sup>	weber per seventy-ninth power of meter	m <sup>92</sup> /s <sup>2</sup>	ninety-second power of meter per second squared
Wb/m <sup>80</sup>	weber per eightieth power of meter	m <sup>93</sup> /s <sup>2</sup>	ninety-third power of meter per second squared
Wb/m <sup>81</sup>	weber per eighty-first power of meter	m <sup>94</sup> /s <sup>2</sup>	ninety-fourth power of meter per second squared
Wb/m <sup>82</sup>	weber per eighty-second power of meter	m <sup>95</sup> /s <sup>2</sup>	ninety-fifth power of meter per second squared
Wb/m <sup>83</sup>	weber per eighty-third power of meter	m <sup>96</sup> /s <sup>2</sup>	ninety-sixth power of meter per second squared
Wb/m <sup>84</sup>	weber per eighty-fourth power of meter	m <sup>97</sup> /s <sup>2</sup>	ninety-seventh power of meter per second squared
Wb/m <sup>85</sup>	weber per eighty-fifth power of meter	m <sup>98</sup> /s <sup>2</sup>	ninety-eighth power of meter per second squared
Wb/m <sup>86</sup>	weber per eighty-sixth power of meter	m <sup>99</sup> /s <sup>2</sup>	ninety-ninth power of meter per second squared
Wb/m <sup>87</sup>	weber per eighty-seventh power of meter	m <sup>100</sup> /s <sup>2</sup>	hundredth power of meter per second squared

# METRIC SYSTEM

## BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

## SUPPLEMENTARY UNITS:

plane angle	radian	rad	...
solid angle	steradian	sr	...

## DERIVED UNITS:

Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
electric potential difference	volt	V	W/A
electric resistance	ohm	...	V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m/s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

## SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10 <sup>12</sup>	tera	T
1 000 000 000 = 10 <sup>9</sup>	giga	G
1 000 000 = 10 <sup>6</sup>	mega	M
1 000 = 10 <sup>3</sup>	kilo	k
100 = 10 <sup>2</sup>	hecto*	h
10 = 10 <sup>1</sup>	deka*	da
0.1 = 10 <sup>-1</sup>	deci*	d
0.01 = 10 <sup>-2</sup>	centi*	c
0.001 = 10 <sup>-3</sup>	milli	m
0.000 001 = 10 <sup>-6</sup>	micro	μ
0.000 000 001 = 10 <sup>-9</sup>	nano	n
0.000 000 000 001 = 10 <sup>-12</sup>	pico	p
0.000 000 000 000 001 = 10 <sup>-15</sup>	femto	f
0.000 000 000 000 000 001 = 10 <sup>-18</sup>	atto	a

\* To be avoided where possible.

# **MISSION** *of* **Rome Air Development Center**

**RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C<sup>3</sup>) activities, and in the C<sup>3</sup> areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.**

